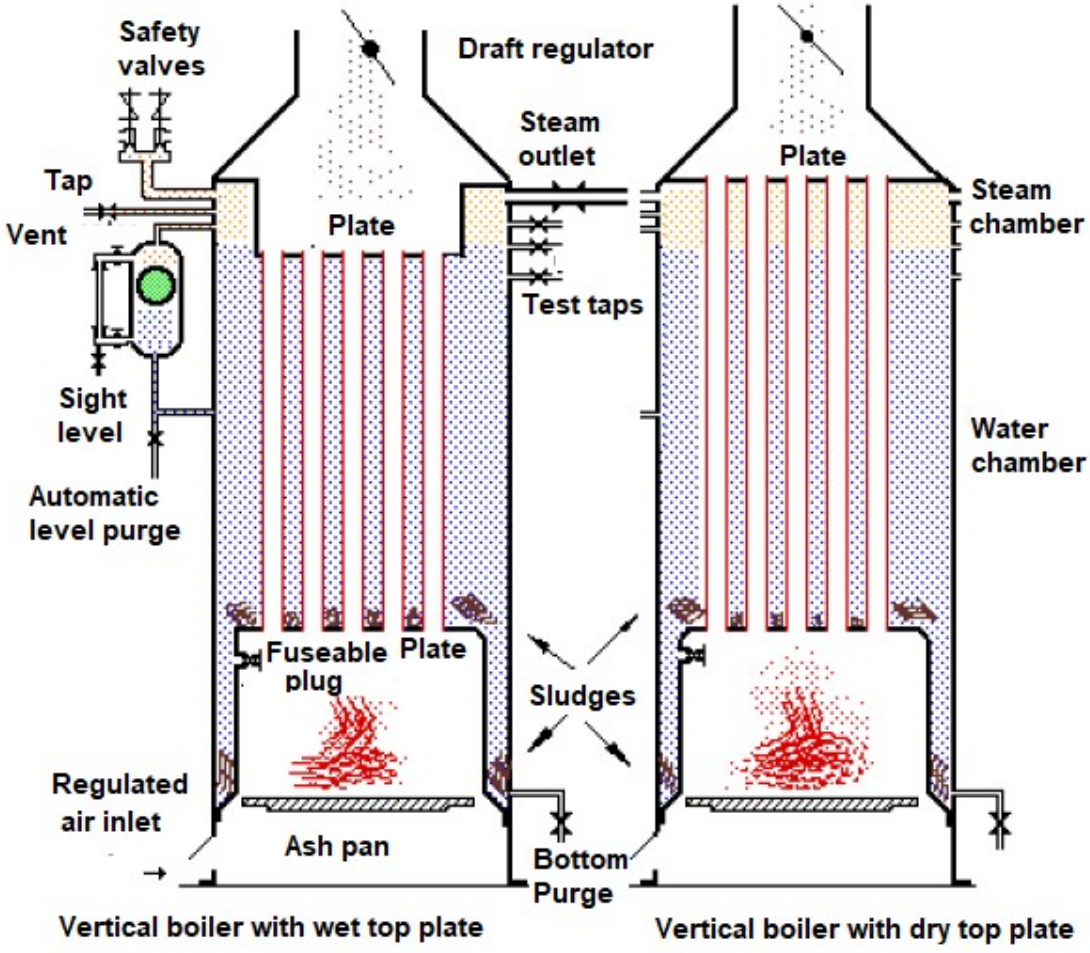
CHAPTER 5: Operation Part 5

VERTICAL FIRE WOOD BOILERS

If we consider vertical boilers, in this case they will generally be single-pass (a very short firebox pass and a tube pass, although in the past they were practically just a vertical cylindrical firebox with some large-diameter tubes that passed through it at an angle to allow the sludge to fall through, since it received heat from the firebox flame and could burn due to lack of cooling when clogged with sludge), as the firebox and the tubes are oriented in the same direction (although there are vertical boilers with more than one pass, they are not very common).

Let's look at a diagram for wood combustion (single-pass) in the boiler's firebox and evaluate its overall performance.



Vertical wood-fired boilers, which generally have low steam output (typically around 1,000 kg/hour), have both advantages and disadvantages.

Their primary advantage is usually the lower initial cost and ease of installation (generally requiring only a flat floor to support their weight and a chimney outlet in the roof).
Their primary disadvantage is their low efficiency or heat utilization.

Because they are single-pass (limited in the gas flow path), and because they are vertical single-pass systems, the chimney draft is very pronounced (although it can be easily regulated). **The "residence time" of the gases in the boiler is very short, resulting in low heat transfer and a high flue gas temperature at the boiler outlet.**

In two boilers with different flue gas temperatures, under the same combustion and fuel conditions, the boiler with the lower flue gas temperature has better heat utilization—higher efficiency—because the heat lost through the chimney is directly proportional to the flue gas temperature.

In the case of wood, single-pass vertical boilers generally produce less than 4 kg of steam per kg of dry wood (with 25% HB, and close to 3 kg/kg of wood in most cases, due to the loss we will explain below).

However, there is a loss that is not taken into account: the tubes are positioned so high above the combustion chamber that they draw in the flame (the flame consists of the combustible gases produced by the decomposition of the wood by heat, organic gases at different stages of transformation, including CO).

As we have said, the flame, upon entering the inside of the tubes, is extinguished, resulting in a significant energy loss of unburned gases (which can be measured in the chimney, but are not visible because, since wood gases do not produce smoke like fuel oil, the same occurs with natural gas and bottled gas).

This energy loss due to "unburned gases" can be very significant at certain times (when the boiler is operating at high loads, when there is a lot of wood in the firebox, when the wood has a high moisture content, when operating with insufficient excess air, etc.).

We mentioned that for every 1% of carbon monoxide (CO) in the chimney, between 5% and 7% of the wood is lost, but the boiler also "shrinks."

This is because the flame loses temperature in the firebox, thus transmitting less heat; the wood occupies a large part of the firebox, which then stops absorbing heat as it blocks and fouls the heat transfer surfaces; the boiler gets dirty quickly, which causes the chimney temperature to rise and further heat loss, etc.

The other problem to consider is that if the vertical boiler is a "dry" plate type (the top plate is in the steam chamber, with some of the tubes not cooled by the boiler water**), there is a high probability of tube loosening and cracking, as well as plate cracking between the tube holes.** This problem usually occurs during startup.

Since there is no steam in the steam chamber to cool the tubes and plates, when the boiler is cold and started up, the strong draft will cause a significant increase in combustion if care isn't taken to ensure slow combustion (gentle combustion, allowing time for the boiler to preheat at low combustion).

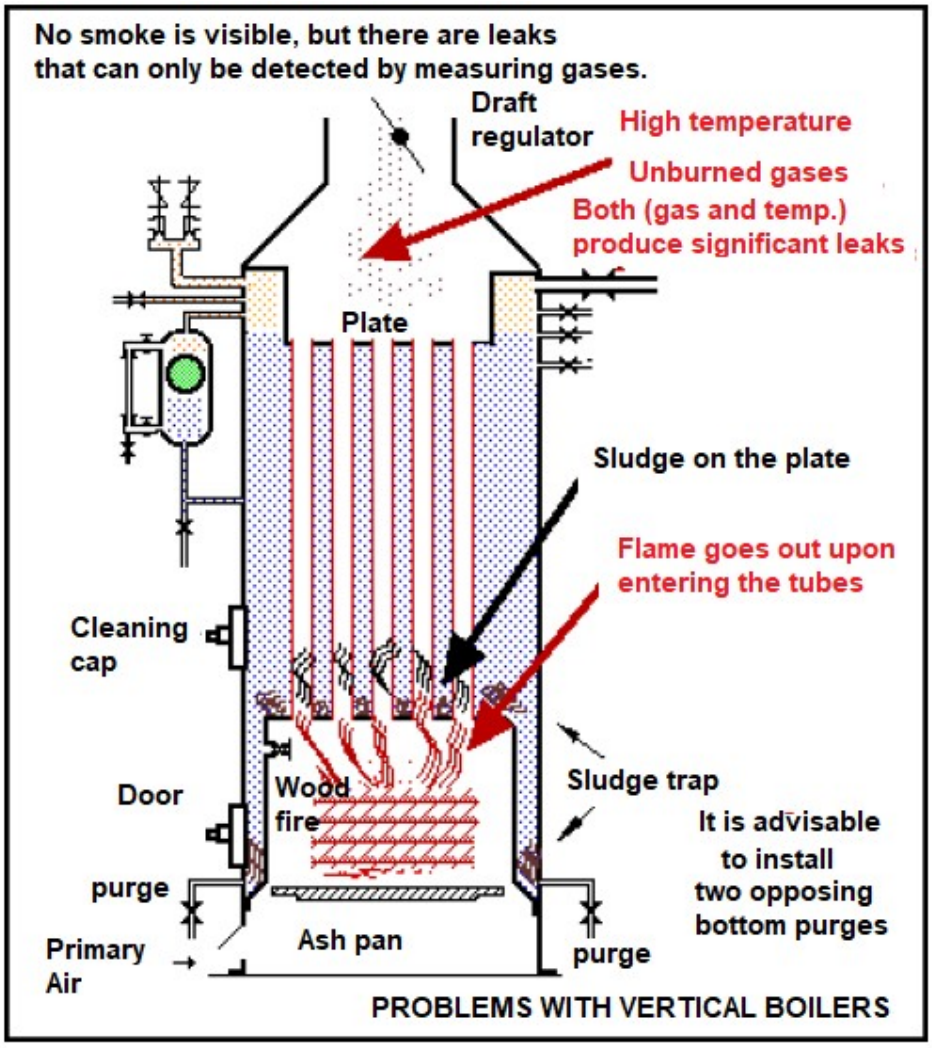
The flue gas temperature becomes very high, causing the tube mandrels (and welds) to overheat on the plates. This leads to "thermal fatigue" or overheating, which can cause the metal to "burn" or "soften," resulting in loosening or cracking of the tubes.

It's important to remember that as the boiler heats up, temperature differences cause expansion and contraction, creating significant stress between the plates, tubes, and shell. This can range from a simple stress crack to cyclic stress fatigue that ultimately leads to a crack.

Another disadvantage is that the water treatment must be designed to prevent internal sludge buildup, as this sludge partially falls onto the lower plate, which is directly exposed to the heat of the flame.

This can cause cooling problems (this sludge is very difficult to remove because the plate is horizontal and has vertical tubes, making it difficult for the sludge to flow down to the side drain for removal via the bottom purges).

It is advisable to have two opposing purges and to perform regular manual cleaning with internal hoses. This keeps the lower plate clean. For this purpose, hand or head access points should be provided at the level of the lower plate, positioned opposite each other to allow for hose cleaning of the entire plate.



As we can see in the previous figure, showing the sludge deposited on the lower plate (which can cause it to overheat), the upper plate is wet (it cools down), and we can see that the boiler is not completing combustion correctly. The flame penetrates the tubes and goes out, causing energy losses due to unburned gases.

We can see that we have installed two opposing bottom purges and cleaning plugs.

In summary: vertical boilers are cheaper, but generally have poor efficiency. It's important that the combustion chamber is tall enough to prevent the flame from penetrating the tubes.

The filter system can be dry or a system of pipes with water circulation (the problem with the latter is that if the chemical treatment produces sludge, the pipes can burn out when clogged with sludge if they don't have sufficient slope and the purges don't remove it).

To prevent sludge, the water must be softened (the salts that cause precipitation, generally calcium and magnesium bicarbonates, must be exchanged for sodium) or these salts must be removed with reverse osmosis (or by external chemical means).

AIR AND CHIMNEYS IN WOOD-BURNING BOILERS

In wood combustion, the air intake due to the chimney draft or the induced draft fan controls the combustion process. Since the amount of wood present is much greater than what is being burned instantaneously on the grate or grates, the combustion rate depends on the amount of air that comes into contact with the wood. **Similarly, combustion is stopped by completely cutting off all contact between the air and the wood.**

This last operation is very important when it is necessary to completely stop combustion due to a low water level.

When closed in these cases, air inlets must be very airtight.

Forced draft fans or air inlets below and above the grille depend on the negative pressure in the home (generally around -3 to -10 mmWC) and the primary, secondary, tertiary, etc., air fans.

Generally speaking**, the primary air under the grate (and secondary air) for combustion is adjusted according to the steam demand (regulated by the steam pressure)**.

Induced draft (chimney flue gas management) is controlled by the negative pressure in the combustion chamber (although this isn't always the case, as there are other alternatives).

In these other cases, different alternatives are adapted to each specific situation.

It is very important, then, before analyzing all types of wood-burning boilers, to explain how the combustion gases are carried to the chimney and how the

combustion air (primary and secondary) enters, because this largely defines the behavior of wood-burning boilers.

Although they all have in common **that the combustion chamber is under negative pressure** (that is, below atmospheric pressure, negative gauge pressure, so that gases do not escape through the wood loading inlets, sight glasses, ash pan covers, etc.).

This negative pressure is generally measured in millimeters of water column (mm w.c.) or millibars (1 mbar being approximately equivalent to 10 mm w.c.).

To measure this depression (or pressure, if present), a U-shaped tube with a diameter of several millimeters (for example, 10 mm) can be used. The transparent ends, made of glass or plastic, should be 300 or 400 mm long, with one end open to the atmosphere.

The other end should be connected to a copper pipe or similar (for example, 1/4" or similar), which should be connected through a well-sealed hole to the flue or chamber being measured. If a good seal is not possible, the copper pipe should be inserted into the chamber so that it is within the chamber being measured.

The U-shaped tube should be filled with water (with a few drops of alcohol and, if desired, a small amount of color dye, ink, or similar substance).

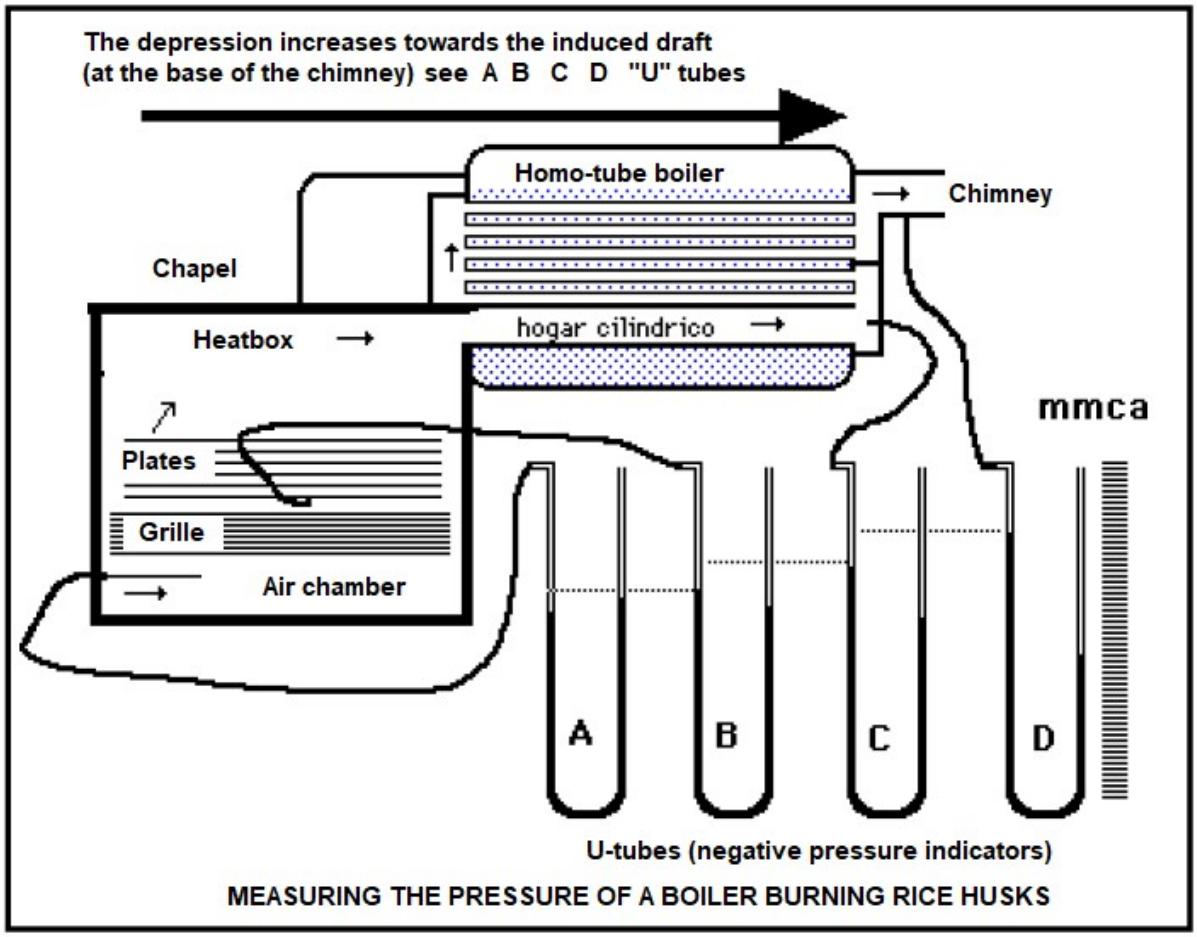
The end connected to the boiler, if there is a vacuum, will try to "suck" the water towards that end (it is actually the atmospheric pressure that "pushes" the other end, because its air pressure is greater than the chamber under vacuum), if there is air pressure in the chamber, the effect is the reverse.

The difference measured between the parallel part of the "U", in a vertical form (like a "plumb line") measured in millimeters with a ruler or meter) is the depression (in mm.c.a.).

In a combustion chamber, the draft will generally be -4 mm to -10 mm, but as we approach the chimney or induced draft, the depression increases (there is more "vacuum," meaning greater draft).

When the draft is natural, this depression is generally low (at the base of the chimney it can be from -10 mm to -20 mm, if the chimney is taller and the flue gas temperature is higher).

With an "induced draft" fan, it can be much higher, with the pressure at the fan inlet varying from -50 mmWC to more than -250 mmWC, depending on the type of fan, revolutions per minute, rotor diameter, etc., and how the air intake in the combustion chamber is regulated, or the penetrations due to leaks in the smoke box seals).



MEASURING THE PRESSURE OF A BOILER BURNING RICE HUSKS

As we can see in the graph above, the depressions increase towards the chimney flue (natural or fan induced).

1-Natural Draft in the Chimney:

Natural draft, as the name suggests, is the **"vacuum" that the hottest gases tend to create at the base of the chimney** as they travel through the flue (in reality, it is atmospheric pressure that pushes the air into the combustion chamber as the hottest air moves vertically through the chimney).

Since air decreases in weight (density) as it heats up, air in a boiler room might weigh about 1.3 kg/m³, but when heated to the boiler outlet temperature or chimney inlet temperature, it drops to about 0.525 kg/m³ at 400°C 752°F, although the chimney temperature is generally between 250°C 482°F and 350°C 662°F in naturally draft boilers.

The draft is equal to the difference between the weight of a volume of atmospheric air equal to that of the chimney and the weight of the hot gases it contains. Therefore, the taller the chimney (assuming the gases don't cool down and the chimney diameter is adequate), the greater the draft at the base of the chimney.

This draft is regulated in the chimney by means of a butterfly valve or by introducing cold air from the outside, in order to maintain adequate negative pressure or draft in the combustion chamber.

It's important to remember that the volume of gases needs a cross-section in the chimney to pass through. If the chimney becomes clogged and this passage narrows, the boiler loses draft and combustion is insufficient (the boiler's steam production capacity decreases).

The primary and secondary (or tertiary) air intakes are regulated along with the draft, by means of butterfly valves or dampers, located under the ash pan, above the grate, etc.

We can say that for a 10 m high chimney, when the gases have an average temperature of 250°C (485°F), the theoretical draft at the base is -5.4 mm w/w. If we double the height to 20 m, the draft will double, or -10.8 mm w/w.

The same can be said of the temperature: if we increase it to 300°C (662°F), in both height cases we will have -6 mm w/w and -12 mm w/w.

However, if the chimney cools down in winter to 150°C (302°F), the draft drops to -3.8 mm w/w and -7.6 mm w/w.

These theoretical values are what we would obtain if we closed the air intake to the boiler (and there were no other air leaks). At that moment, an instant before the temperature in the chimney drops, the "theoretical draft" occurs.

However, when we open the primary and secondary air intakes, the "work" of "circulating" the air and then the gases through the different sections of the boiler (where there are restrictions, such as the grate, tubes, regulators, etc.) causes a "restrictive work" to occur. This results in a loss of part of the theoretical draft, and we obtain the "actual draft."

That is, the draft we will measure in the combustion chamber (there is also energy or work expended in the circulation of the gases themselves, energy that will later be used to raise the gases to the atmosphere).

Conclusion:
If the chimney is low, has a small cross-section (meaning more air is expended to overcome the lack of cross-section), or the gases cool down, the draft will be weak, resulting in poor combustion and a slow response from the boiler (to increased steam production).

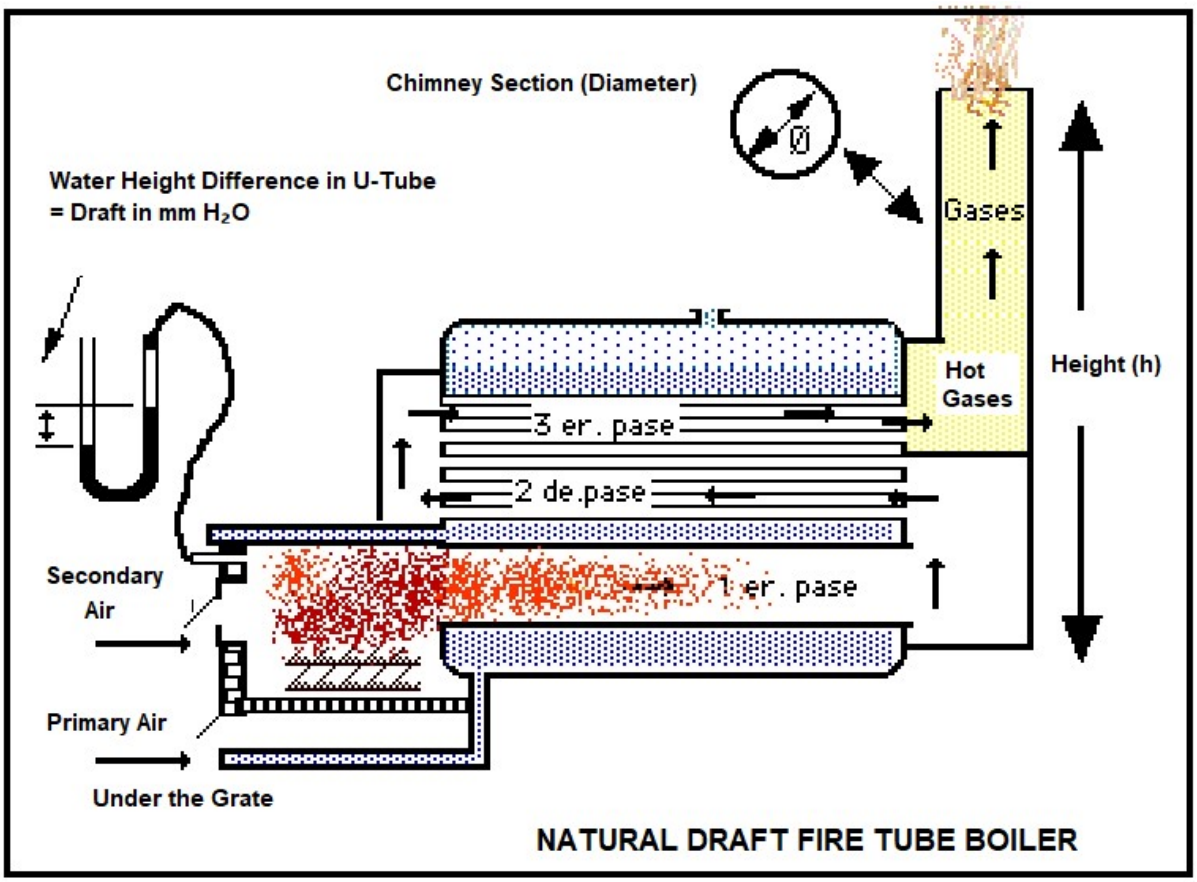
Especially when burning wood with high moisture content, a good draft is necessary, as it requires more air than dry wood, and the firebox is usually loaded with more wood to compensate for the lack of combustion.

Therefore, the chimney must have the appropriate cross-section (diameter), height, and insulation against the cold winter winds (which cool the gases in the chimney section).

In natural draft systems, primary and secondary air generally enter through the negative pressure in the home (that is, it is not "pushed" by a fan, but rather "drawn" by the negative pressure in the home), so the amount of air that enters depends on the "opening" of the air inlet and the negative pressure in the home (the greater the negative pressure, the greater the "force" for the air to enter from the boiler room).

This is how the amount of combustion is regulated, since the amount of wood inside the boiler remains constant. The amount of combustion or fire depends on the amount of primary air (under the grate or firebox in some cases) and secondary air (the secondary air is the air that enters above the grate.

Or in many cases, the excess air from the grate itself, which is used to "finish" the combustion started by the primary air, which also has an excess, that of the grate, often sufficient for complete combustion).



This highlights the importance of the chimney's dimensions, both in height and cross-section, and to prevent the gases from cooling down.

It also emphasizes the need to prevent air from entering through leaks in areas not essential for combustion (loading ports, cleaning ports, firebox linings—both refractory and pipe—flue boxes, chimney base, etc.).

In some cases, the primary air can be forced in by a fan (always maintaining negative pressure in the combustion chamber). In this scenario, the negative pressure in the combustion chamber is kept constant, and the amount of air forced in by the primary fan is varied.

2- FORCED DRAFT (or “INDUCED DRAFT”).

Natural draft boilers do not have a strong draft due to limitations in chimney height and cross-section, and the need for high flue gas temperatures. This results in a loss of efficiency, since the hot gases carry away the heat that could be used to improve performance.

Natural draft boilers generally have one or two gas passes, such as single-pass vertical boilers, two-pass fire-tube boilers, or two-pass water-tube boilers (older sectional boilers with semi-horizontal tubes).

Since boilers must maximize the use of the heat produced, minimizing their size (making them more efficient with less material) requires increasing the number of gas passes, installing heat recovery systems (such as economizers, i.e., feedwater heaters or heaters for other uses, or recovery heaters to heat the combustion air), or increasing the response time to changes in steam consumption.

All of this means that natural draft is no longer sufficient, so forced draft (the suction and propulsion of hot gases by mechanical means) is used.

The term “forced” draft can refer to a series of systems in which the air is forced (as in the old case of pressurized boiler rooms, generally applied in ships, pushing the air and preventing the gases from escaping into the boiler room) or by sucking the gases out by mechanical means (fans) or by means of air or steam inductors.

As in the case of locomotives, where a draft is created with a steam injector as if it were a "venturi," that is, a "jet" of steam is discharged into a narrower section of the chimney through a nozzle.

This steam "drags" the gases, making them gain speed, which forces an increase in the capacity of the chimney and therefore the "draft" at its base, as happens in movies where steam "locomotives" appear; when they are working hard, the chimney is seen with very overloaded smoke. The steam that is generally used is from the discharge of the machine's own cylinders or pistons, so as not to waste extra steam, since the water in the steam is not recovered.

But, in our case, we will generally call it **“induced draft” when a fan (extractor, mechanical, driven by an electric or steam motor: turbine or reciprocating machine) placed between the boiler and the chimney (or between the heat recuperators and the chimney), “sucks” the gases and “pushes” them to the chimney.**

The combination of induced draft and forced air (or forced air: secondary and tertiary forced air under the grate) allows for heat recovery from the flue gases, facilitates the supply of all combustion air under all conditions, and ensures the use of all air passes and heat recovery systems, **maintaining suction in all sections to prevent gas losses and emissions into the boiler room.**

This is especially crucial for wood-burning stoves, as the wood must be loaded through an inlet exposed to the boiler room, and because wood fumes can be polluting and even toxic (the presence of CO—carbon monoxide—which is toxic upon accumulation).

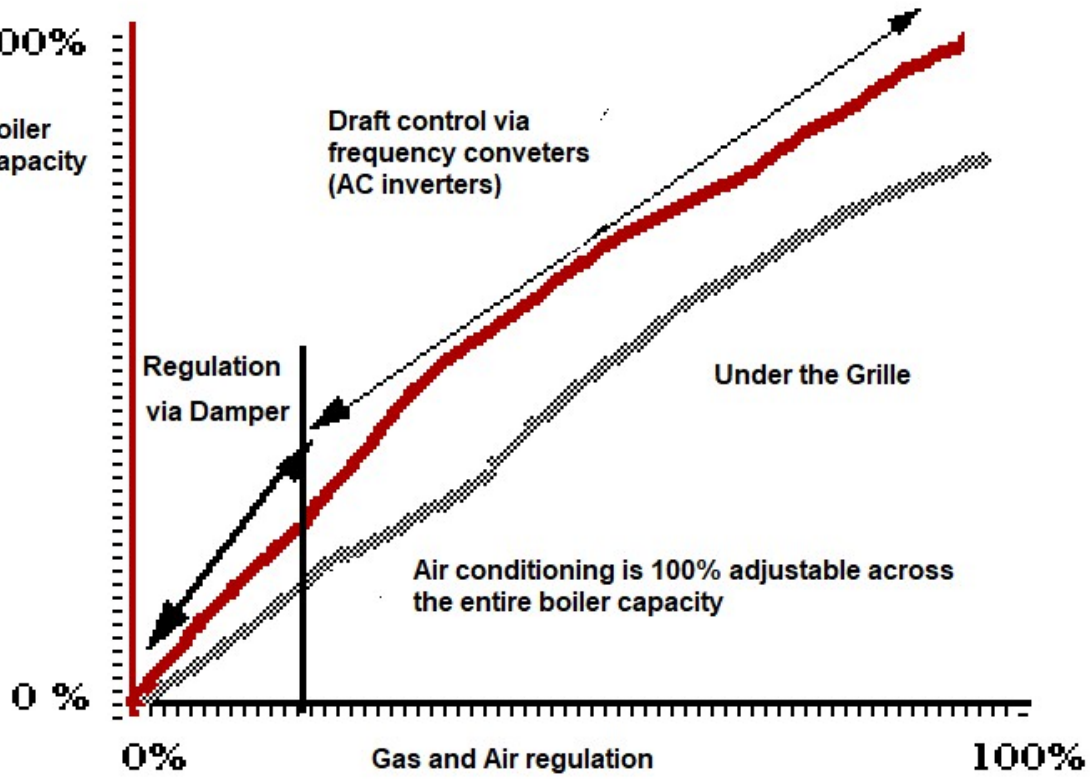
In wood-fired boilers, combustion gases must not be allowed to contaminate the premises where personnel work (due to the CO that may exist in some circumstances or stages of combustion, with other "unburned" gases that may be harmful to health).

Generally, the "induced draft" (chimney fan) automatically (or manually) maintains the negative pressure in the combustion chamber (from approximately -4 mmWC to about -10 mWC), varying its capacity by means of a gas valve (shutters or butterfly valve at the fan inlet), or by varying the speed of the fan rotor (by means of a mechanical variator or an electronic frequency variator of the alternating current that powers the fan motor, thus varying its rotation speed or rpm).

Although we recommend combining modulating "shutter" control with motor frequency converters, because the converters (AC inverters) alone do not regulate from 0% to 100%, but rather in increments that can be 30% or more, making it difficult to accurately regulate both the air below the grate (primary) and above the grate (secondary or tertiary), or the induced draft in the chimney.

This allows maintaining combustion chamber negative pressure at different loads, and what is varied to increase or decrease combustion are the primary, secondary, and tertiary air fans. The induced draft follows the flow rate of these fans, maintaining the preset negative pressure in the

combustion chamber.



When the boiler only has "induced draft," combustion capacity is achieved through the negative pressure in the combustion chamber created by the induced draft. The draft is increased or decreased according to the combustion air requirement. This is complemented by the regulation of primary and secondary air intakes via the intake valves.

"IN "INDUCED DRAFT" SYSTEMS, THE WOOD LOADING INLET OR THE SIGHTS SHOULD NOT BE OPENED WHEN THE INDUCED DRAFT IS OFF."

If the induced draft is off, the hearth is full of "half-burned gases," which, when an air inlet (viewing windows or wood loading door) is opened, allows oxygen to enter and mix with the unburned gases, potentially causing a hearth explosion and/or a "flame" to shoot out towards the person who opened the viewing window or loading door. THIS IS VERY DANGEROUS!

In some cases, **it is advisable to install a safety system, an interlock, that prevents the opening of the wood loading door if the induced draft is turned off** (especially when burning sawdust).

It is always advisable that, with the induced draft turned off, a small amount of natural gas venting be allowed through the draft fan. This is for the default "sweeping" of the gases.

A slight negative pressure in the combustion chamber prevents gases from escaping into the boiler room.

This especially true when the primary, secondary, and tertiary air intakes do not close and seal properly or shut off if forced, including the induced draft. This situation can occur when the steam is cut off due to high pressure, as it should be, but some air continues to enter, or if the induced draft shuts off for any other reason.

This default "purge" ensures that gases such as CO do not escape into the boiler room, although this small air intake causes a small amount of vaporization, meaning that the boiler does not "shut down" completely; it continues to generate steam and build pressure if there is no consumption, but this generally does not represent a problem unless there is a significant drop in pressure.

It's also important to consider that the wood loading systems should be as airtight as possible as possible while the wood is being loaded into the combustion chamber, since the incoming air doesn't contribute to combustion (it's air that enters and "steals heat").

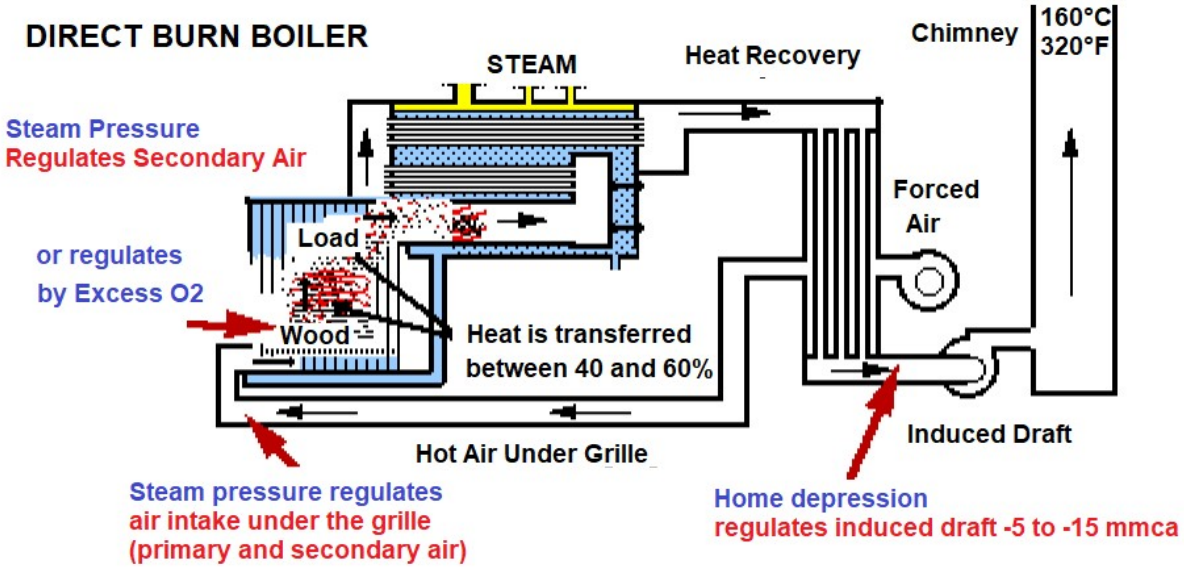
Air exiting through the chimney accelerates the chimney's induced draft to achieve the desired negative pressure, but even so, a lack of negative pressure affects combustion and can lower the boiler's steam pressure (air doesn't enter the combustion zone, i.e., between the wood on the grate; there's an excess of air that consumes heat, etc.).

But the most objectionable aspect of these systems is that they expose the operator to a combustion chamber explosion (which can be caused by a mixture of gases with incoming air, or by any other cause, or simply by the explosion of a chamber tube due to poor circulation or insufficient wall thickness caused by corrosion from combustion over years of use).

Although these "double-lid" or "double-door" magazines, with their doors interlocked, must be constructed in such a way that the upper, or outer, lid locks into place when the lower loading lid opens, otherwise, if this outer lid opens during an explosion, the operator will not be protected.

Some wood-burning boxes have an outer loading lid that tends to jam in the event of an explosion. These boxes typically have two compartments: one above the outer lid where the wood is pre-loaded and then transferred to the intermediate chamber. The outer lid is then closed and locked against a sturdy frame, allowing the loading lid directly into the combustion chamber to be opened.

These lids, which are in contact with the combustion chamber, are usually made of special cast iron, and both are operated pneumatically or hydraulically.



Induced draft is generally controlled by a combustion chamber pressure sensor (which maintains the pressure between -4 mmWC and -10 mmWC), and forced draft is controlled by pressure switches connected to the steam pressure.

There is also a high-pressure steam cutoff switch for both forced and induced draft (blocking the forced draft fans to prevent positive pressure in the combustion chamber; that is, the forced draft can never ignite if there is insufficient vacuum in the chamber). See below: Pressure Switches.